

Plant cover effect on Bolson tortoise (*Gopherus flavomarginatus* Legler 1959, Testudinidae) burrow use

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Abstract

The Bolson tortoise, *Gopherus flavomarginatus*, occurs within a restricted geographical area in the Mexican Chihuahuan Desert. We analyzed the variation in surface microhabitat with relation to the burrow occupancy for this tortoise at the Mapimí Biosphere Reserve, Mexico. In summer 2010, we monitored burrow activity (active, inactive, or abandoned) and measured environmental factors that might influence the burrow's occupancy by tortoises (air temperature, relative humidity and substrate temperature, both inside and outside the burrow, and the plant cover around it). Discriminant analysis was used to identify the importance of these variables influencing burrow occupancy. Correlation and linear regression analyses were performed to quantify the relation between environmental factors in the sampled burrows.

Results. Sixty-one burrows were identified at the Tortugas locality. The first function's auto-value analysis indicates that this function explains 97.9% of the variation in burrow activity status; high occupancy scores were associated with low substrate temperature inside the burrow. Plant cover was inversely proportional to substrate temperature inside the burrow. These results suggest the importance the density of plants surrounding the tortoise's burrow as a key factor influencing the burrow microclimate and occupancy by the tortoises.

Conclusions. *Gopherus flavomarginatus* inhabits burrows, in part, based on microhabitat structure, with plant cover being a main factor influencing burrow occupancy. Our findings indicate that human land use and vegetation management are important for conserving Bolson tortoises, and for understanding habitat conditions necessary for the successful establishment of populations elsewhere.

Keywords

Gopherus flavomarginatus, burrow, plant cover, habitat, temperature, microclimate

Introduction

Research on the ecology of ectothermic organisms has established the importance of vegetation structure for their microhabitat selection (Hertz et al. 1994, Vitt et al. 1997, Litzgus and Brooks 2000, Bryant et al. 2002). Changes in vegetation produce variations in other microhabitat attributes, like light intensity, wind speed, air and soil temperatures (Pringle et al. 2003). Variation in these features influences thermoregulatory behaviors and activity levels in ectotherms (Adams and Decarvalho 1984, Huey 1982, 1991, Huey and Kingsolver 1989, Webb et al. 2005, Turbill et al. 2011), resulting in greater impact on species that are thermally sensitive to changes in habitat structure (Walther et al. 2002, Pringle et al. 2003).

Population ecology theory predicts that in a changing environment, a population can adapt to new conditions, migrate to a place that favors its survival, or become extinct (Pease et al. 1989, Pringle et al. 2003) if the species presents a capacity of dispersion and limited evolutionary responses (Allendorf and Luikart 2007). Long term studies have established relationships between changes in vegetation density and animal movements and extirpations of populations with small distributions (Fitch 1999, Pringle et al. 2003). For example, abundances of forest birds in New Hampshire decreased considerably over a period of 30 years causing local extinction of four species; the most important local factor affecting bird abundance was temporal change in forest vegetation structure (Holmes and Sherry 2001). Likewise, it has been reported that for *Gopherus polyphemus* in sites invaded by an introduced weed, tortoises avoided areas where weeds had formed a dense monoculture, suggesting that habitat selection increases isolating effect of habitat fragmentation on this tortoise (McCoy et al. 2013).

The Bolson tortoise, *Gopherus flavomarginatus* (Figure 1), is North America's least studied tortoise; it is considered as Vulnerable by IUCN Red List (2015), and has a geographical distribution restricted to the Mapimí Basin in the Mexican Chihuahuan Desert (Aguirre et al. 1984). This restricted distribution is likely due to specific habitat requirements (Aguirre et al. 1997), including constant temperatures and humidity levels provided by their burrows throughout the year, as *G. flavomarginatus* seems to have a limited thermoregulation capacity (Adest et al. 1989); Adult individuals of this species have a high fidelity to their burrow, spending about 95% of their life hibernating or aestivating within this structure, and remain only 5% outside of them during the summer season (Adest et al. 1989, Lovich and Daniels 2000, Daren-Riedle et al. 2008), and adult tortoises are unlikely to be naturally depredated (Treviño et al. 1995).

Therefore, if Bolson tortoise requires specific microclimatic conditions to inhabit burrows and survive, variations in microhabitat are expected to influence either their use or abandonment. An analysis of microhabitat variation is shown here in relation to the occupation of burrows of *G. flavomarginatus*. Our objectives included: 1) charac-



Figure 1. *Gopherus flavomarginatus* (Bolson tortoise).

terization of the environmental factors of air temperature, relative humidity, substrate temperature and pH; physical factors of width and height of burrows and 2) determine how these factors are related to plant cover and occupancy of burrows. This information can increase understanding of this species' response to variation among microhabitats, and support conservation efforts for this species.

Methods

The 100 hectare study site, Tortugas, is located in the south-central portion of the Mapimí Biosphere Reserve, in Mexico (26°00', 26°10'N and 104°10', 103°20'W; CONANP 2006) and within the region known as the Mapimí Basin (Figure 2). The reserve encompasses parts of the municipalities of Tlahualilo and Mapimí in the State of Durango, Sierra Jimenez in Chihuahua, and Sierra Mojada in Coahuila. The site is located at an altitude of 1000–1200 m in the lowlands up to 2000 m and provides numerous exposures of volcanic and chalky origin and sand dunes (Ramírez-Carballo and Pedroza-Sandoval 2011). A semi-hot desert climate prevails (2.8°C in winter to 36.3°C in summer), with an annual mean precipitation of 145.88 mm (CNA 2007) concentrated in summer (from June to September).

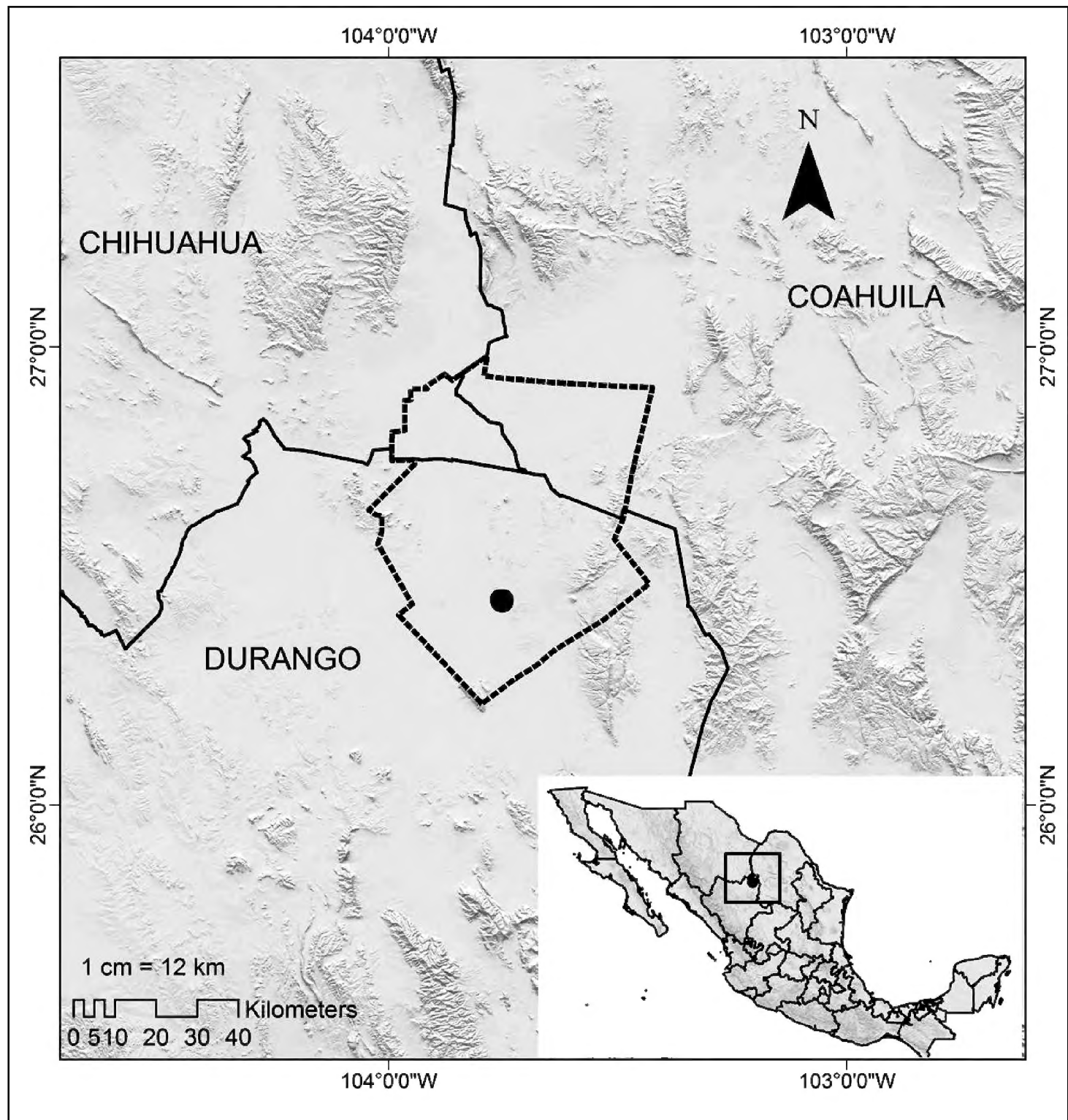


Figure 2. Study site. The black circle show Tortugas locality, in dotted lines is show The Mapimí Biosphere Reserve and continuous lines the state limits.

At Tortugas, we followed the monitoring protocol established by CONANP to find adult tortoise burrows (CONANP 2006). Burrow monitoring was performed during two consecutive days in summer (September, 2010). There was no rainfall before or after those two days. We classified burrow occupancy (active, inactive, or abandoned) based on measuring external characteristics according to Auffenberg and Franz (1982) and Cox et al. (1987). Accordingly, an active burrow shows foot or plastron prints on the access tunnel and the surrounding mound; the soil is loose, with little compaction. In an inactive burrow, no tortoise tracks are seen, and soil at the burrow's entrance and the mound looks compacted. Finally, an abandoned burrow entrance shows an accumulation of debris, such as branches, grass, cobwebs, and the soil of the mound is clearly compacted.

In every burrow, was measured microhabitat structure considering the variables width (W) and height (H) of the entrance and the substrate's pH 30 cm inside. Dataloggers (Datalogger USB-WK057, accuracy: ± 1.0) were used to measure environmental factors continuously, including air temperature (T_a) and relative humidity (RH) inside (30 cm depth) and outside (30 cm above surface) the burrow, except pH, all environmental data were recorded each hour for 24 hours; substrate temperature inside the burrow (T_s) was also recorded using dataloggers (in contact with the surface). Also, we measured plant cover (PC) using an ellipse area formula ($\pi \times a \times b/4$, where a = major axis and b = minor axis), within three meters of each burrow.

Discriminant analysis was used to determine which habitat and environmental factors differentiate burrows categorized by their occupancy status. Normality was not achieved (Kolmogorov-Smirnov tests; $P \leq 0.05$) and we transformed the continuous data (W, H, pH, T_a , RH, T_s) with the logarithmic formula ($X' = \text{LOG}_{10}(X + 1)$), and PC with the arcsine formula ($X' = \text{Arcsin}\sqrt{X}$), according to Zar (1999). A *Post Hoc* test (LSD) was performed to identify differences among the averages of the three status groups. Lastly, correlation and linear regression analyses were performed to quantify the relation between significant environmental factors and PC in the sampled burrows and was plotted temporal variation of temperature. All statistical analyses were made using STATISTICA 10.0 (StatSoft 2011) software and considered statistically significant at $P \leq 0.05$.

List of abbreviations

W	burrow width
H	burrow height
T_{ai}	air temperature inside the burrow
T_{ao}	air temperature outside the burrow
RH_i	relative humidity inside the burrow
RH_o	relative humidity outside the burrow
T_{si}	substrate temperature inside the burrow
PC	plant cover
LSD	least significant difference
d.f.	degrees of freedom
SD	standard deviation

Results

We located and measured a total of 61 burrows at the Tortugas study site. There was significant difference in the T_{si} among the three types of burrows ($F = 32.40$, d.f. = 2, 58, $P < 0.001$; Table 1). *Post hoc* analysis (LSD) showed that abandoned burrows had higher T_{si} ($\bar{x} = 31.1^\circ\text{C}$, $SD = 5.24$) than active ($\bar{x} = 28.0^\circ\text{C}$, $SD = 4.7$) and inactive ($\bar{x} = 27.0^\circ\text{C}$, $SD = 3.8$) ones (Table 1).

Table 1. Descriptive statistics of environmental factors for active (n = 26), inactive (n = 7), and abandoned (n = 28) burrows, and means comparison tests among burrows categories (d.f. = 2, 58 for all cases). Air temperature inside the burrow (T_{ai}), air temperature outside (T_{ao}), relative humidity inside (RH_i), relative humidity outside (RH_o), substrate temperature inside (T_{si}).

Environmental factor/ Burrow's status	Mean	Standard deviation	Min-Max	Wilks Lambda	F	P
T_{si} (°C)				0.472	32.40	<0.001
Active	28.00	4.72	18.0–37.0			
Inactive	27.00	3.82	24.0–35.0			
Abandoned	31.10	5.24	20.0–43.0			
T_{ai} (°C)				0.995	0.136	0.873
Active	33.74	7.80	15.5–48.1			
Inactive	34.92	6.86	22.0–40.5			
Abandoned	33.47	5.14	20.6–43.8			
T_{ao} (°C)				0.993	0.191	0.827
Active	33.40	7.51	14.8–44.0			
Inactive	34.90	7.15	22.2–41.9			
Abandoned	33.45	4.94	21.0–42.2			
RH_i (%)				0.964	1.090	0.343
Active	29.49	7.29	19.0–51.4			
Inactive	30.65	8.19	20.5–41.5			
Abandoned	34.55	14.37	19.0–75.0			
RH_o (%)				0.984	0.478	0.623
Active	21.48	6.37	14.0–37.1			
Inactive	20.68	5.91	13.4–28.8			
Abandoned	22.30	5.07	15.3–38.0			
pH				0.987	0.384	0.683
Active	7.07	0.57	6.0–8.0			
Inactive	7.0	0.0	7.0–7.0			
Abandoned	6.98	0.28	6.0–8.0			
LC (%)				0.979	0.633	0.535
Active	56.20	26.7	4.9–116.6			
Inactive	59.84	21.71	38.7 - 100			
Abandoned	55.2	21.4	19.8–86.8			
W (cm)				0.978	0.649	0.526
Active	30.73	12.79	14.0–61.0			
Inactive	24.71	8.63	13.0–38.0			
Abandoned	23.75	11.19	12.0–60.0			
H (cm)				0.909	2.915	0.062
Active	21.88	14.02	6.0–75.0			
Inactive	19.57	7.13	9.0–30.0			
Abandoned	15.10	8.12	1.0–46.0			

Results of discriminant analysis were as follows: the first function was statistically significant ($\Lambda = 0.241$, $x^2 = 76.74$, d.f. = 18, $P < 0.001$; n = 61), while the second function was not ($\Lambda = 0.942$, $x^2 = 3.25$, d.f. = 8, $P < 0.917$; n = 61). The first function's auto-value analysis indicates that this function explains 97.9% of the variation in burrow activity status, where T_{si} showed the higher scores (Table 2 and Figure 3).

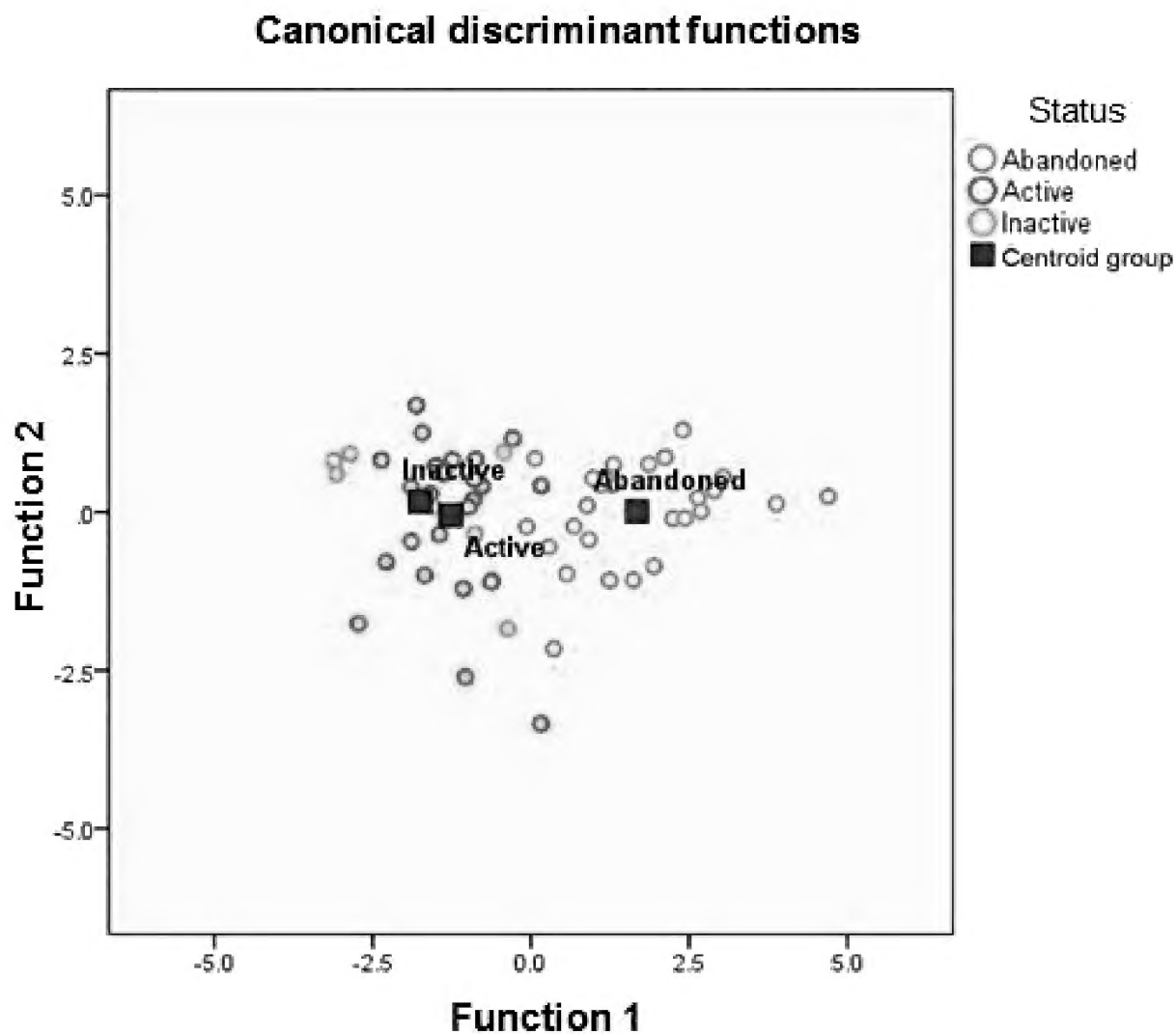


Figure 3. Distribution of the centroids for Bolson tortoise burrows during the summer season.

Table 2. Discriminant canonical function 1 scores with relation to burrow entrance width (W), height (H), air temperature inside the burrow (T_{ai}), air temperature outside (T_{ao}), relative humidity inside (RH_i), relative humidity outside (RH_o), substrate temperature inside (T_{si}), plant cover (PC), and substrate pH.

Environmental factors	Score
T_{si}	621*
H	-.185*
RH_i	.110*
RH_o	.073*
PC	.061
pH	-.054
W	.020
T_{ao}	.009
T_{ai}	-.004

An inverse relationship was observed between PC and T_{si} ($y = -0.2181x + 41.504$), indicating that the higher the plant cover around the burrow, the lower the substrate temperature inside it (Figure 4). Correlation and determination coefficients were high ($R = 0.98$, $R^2 = 0.96$, respectively); plant cover around the burrows influences 96% the

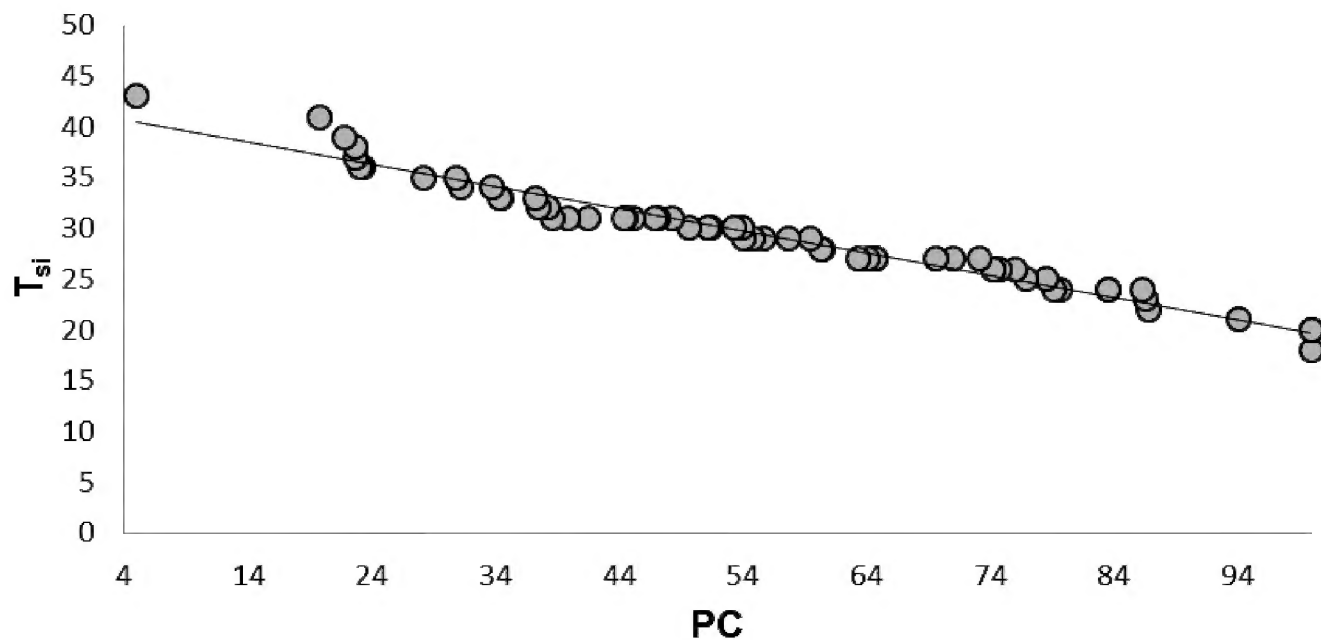


Figure 4. Relation between plant cover (PC) and inner burrow substrate temperature (T_{si}) for *Gopherus flavomarginatus* burrows.

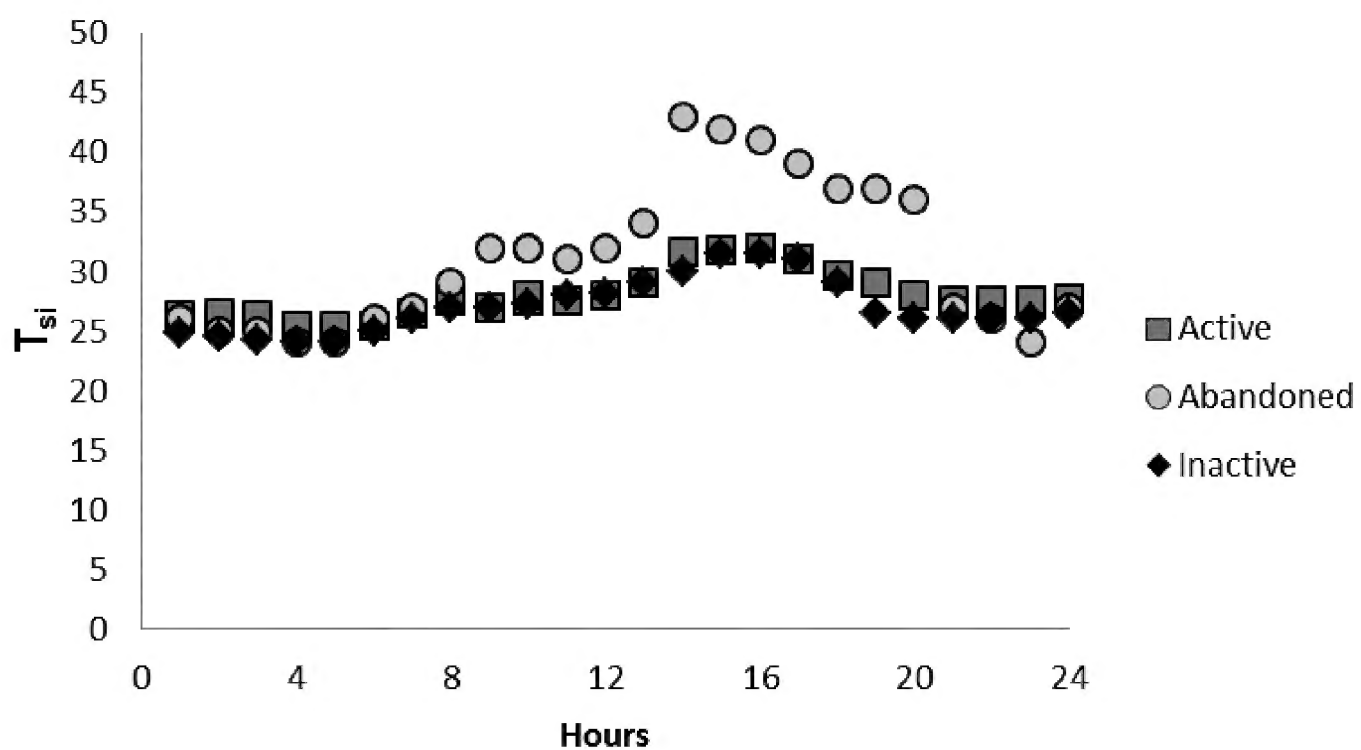


Figure 5. Temporal variation of temperature. T_{si} makes reference to temperature of substrate, squares indicate active burrows, circles make reference to abandoned burrows and rhombus show inactive burrows.

increase of substrate temperature inside the burrows. This relationship was found to be highly significant ($F = 1408.949$, d.f. = 1,59; $P < 0.001$), the temporal variation of temperature is shown in Figure 5.

Discussion

Adest et al. (1989) described individuals of this species emerging from their burrows at night as a response to increasing substrate temperatures inside their burrows ($>34^{\circ}\text{C}$)

because of thermal delay (which it is described as the speed at which the temperature fluctuations penetrate the substrate (Körtner et al. 2008)). Also, they described that around 0700 hr at a distance of 15 cm inside the burrow, the substrate temperature is still above 31°C, while the temperature of an adult individual (7.3 kg) is below 30°C when beginning foraging bouts at the surface. These observations support a hypothesis that the substrate temperature inside *G. flavomarginatus* burrows influences its occupancy dynamics, increasing the possibility of abandonment when the substrate temperature inside these structures consistently is equal to or greater than 31°C.

Our analyses provided evidence that an increase in substrate temperature inside the burrows and their consequent abandonment at our Tortugas study site was correlated with vegetation cover at a scale of 3 m. Aguirre et al. (1984) described that the presence of *G. flavomarginatus* burrows at the Mapimí Biosphere Reserve seemed to be related to shrub type (*Larrea tridentata* (Coville 1893), *Prosopis glandulosa* (Torrey 1827) and grasslands (*Hilaria mutica* (Bentham 1881)). McCoy et al. (2006) and Waddle et al. (2006) reported that habitat quality reduction was the apparent explanation for the increase of abandoned burrows in *G. polyphemus* population in Florida, USA. Additionally, Aresco and Guyer (1999) stated that land cover changes around *G. polyphemus* burrows can result in their abandonment in certain habitats. Similarly, Boglioli et al. (2000), Hermann et al. (2002), Jones and Dorr (2004), Baskaran et al. (2006), and Ashton et al. (2008) all described that for other species of *Gopherus* the presence of burrows is associated with the vegetation, and that the permanent abandonment of these burrows seems to happen as a response to unfavorable habitat conditions.

Moreover, Huey (1982), Hertz et al. (1994), Vitt et al. (1997), and Bryant et al. (2002) mentioned that vegetation structure plays a key role in the activity, feeding, and distribution of some ectothermic organisms. These previous studies support our conclusion that the occupation of *G. flavomarginatus*' burrows are related to microhabitat structure, with vegetation cover being one of the main environmental factors that can affect habitat selection, this interaction of temperature and microhabitat is key to the species' survival. With predicted increasing temperatures as climate change effects become more pronounced in the deserts of America (Friggens 2012), this interaction will be critical over the coming years. On the other hand, we consider that relative humidity inside the burrows is important for Bolson tortoise. However, this variable showed low scores to discriminate activity status of the burrows and did not present significant differences when comparing between activity status; therefore, it was not possible to determine its influence on burrows occupation.

It is important to note that *G. flavomarginatus* might not have originated as a desert ecosystems species, they appeared toward the end of the Tertiary, so they could have spent more than 94% of their evolutionary history during the Quaternary (Pleistocene-Holocene) living in non-desert grasslands (Van Devender and Burgess 1985). Therefore, their current restriction to cool microclimates in their summer burrows could be an extension of a physiology geared to a cooler, more mesic climate. Consequently, it is likely that their thermal physiology and even their social behavior reflect more their burrow microhabitat than the surface environment of the Chihuahuan Desert (Adest et al. 1989).

Conclusions

Having in mind that vegetation cover is a key part of burrows occupancy dynamics for this species, preserving the plant life in regions where *G. flavomarginatus* might potentially colonize or be translocated to in and outside the Mapimí Biosphere Reserve is of critical importance. To achieve this, we need to conceptualize a dynamic reserve (as opposed to a static one that actually exists) that follows ecological succession processes on which this tortoise species survival seems to be strongly dependent.

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